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Effects of an Approach Spacing Flight Deck Tool on Pilot Eyescan

Rosa M. Oseguera-Lohr
Langley Research Center
Hampton, Virginia

Eric D. Nadler
U.S. Department of Transportation
Volpe National Transportation Systems Center
Cambridge, Massachusetts

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National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

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ABSTRACT

An airborne tool has been developed based on the concept of an aircraft maintaining a time-based spacing interval from the preceding aircraft. The Advanced Terminal Area Approach Spacing (ATAAS) tool uses Automatic Dependent Surveillance-Broadcast (ADS-B) aircraft state data to compute a speed command for the ATAAS-equipped aircraft to obtain a required time interval behind another aircraft. The tool and candidate operational procedures were tested in a high-fidelity, full mission simulator with active airline subject pilots flying an arrival scenario using three different modes for speed control. Eyetracker data showed only slight changes in instrument scan patterns, and no significant change in the amount of time spent looking out the window with ATAAS, versus standard Instrument Landing System (ILS) procedures.

ABBREVIATIONS AND ACRONYMS

AATT	Advanced Air Transportation Technologies
ADS-B	Automatic Dependent Surveillance – Broadcast
ARIES	Airborne Research Integrated Experiments System
ATAAS	Advanced Terminal-Area Approach Spacing
ATC	Air Traffic Control
CDU	Control-Display Unit
DAG-TM	Distributed Air/Ground Traffic Management
EADI	Electronic Attitude Director Indicator
FMC	Flight Management Computer
IFD	Integration Flight Deck simulator
ILS	Instrument Landing System
LaRC	Langley Research Center
MCP	Mode Control Panel
NASA	National Aeronautics and Space Administration
ND	Navigation Display
STAR	Standard Terminal Arrival Route
nmi	nautical miles

1.0 Introduction

The Distributed Air/Ground Air Traffic Management (DAG-TM) concept, developed in the National Aeronautics and Space Administration's (NASA) Advanced Air Transportation Technologies (AATT) Project involves various levels of collaboration between airborne and ground-based resources to enable less-restricted and more efficient aircraft trajectories throughout all phases of flight, leading to increased airport capacity[1].

The element of the DAG-TM concept that focuses on terminal area operations requires the development of procedures and technologies that allow aircraft to have more flexibility in choosing an efficient route through the terminal area, while arriving at the runway threshold properly and efficiently spaced from the preceding aircraft[2]. The Approach Spacing concept allows for a safe reduction in the excess spacing in traffic streams from what current procedures allow by increasing the precision with which aircraft can be spaced. This requires the capability to precisely predict and control the spacing intervals between arriving aircraft. To meet this objective, an airborne tool called the Advanced Terminal Area Approach Spacing (ATAAS) tool, was developed at NASA's Langley Research Center (LaRC)[3]. The ATAAS tool was tested in a high-fidelity, full mission engineering simulator, to evaluate workload and pilot acceptability issues associated with its use, and to explore the feasibility of the operational concept. To determine whether using the ATAAS tool diminished the pilots' out-the-window eyescan, an eyetracker was used during the simulation. This document describes the results of the eyetracker data anaylsis. Other study results are reported separately[4].

2.0 Background

The ATAAS tool uses Automatic Dependent Surveillance-Broadcast (ADS-B) aircraft state data along with final approach speeds and wind data to compute speed commands for the ATAAS-equipped aircraft to maintain, in order to achieve the required runway-threshold time interval behind the other aircraft. This tool has undergone extensive Monte Carlo analysis to characterize and refine its performance.

To test the ATAAS tool in a full-mission simulator, a nominal in-trail arrival scenario was developed. Airline subject pilots were recruited to fly the simulator with ATAAS, using three different methods for controlling speed. Aircraft and ATAAS state and mode data were collected, pilot eye movements were recorded, and pilots provided subjective ratings of perceived workload levels and various other aspects of the concept through questionnaires. Appropriate system and operational (crew and controller) procedures, phraseologies and a crew interface with the ATAAS tool were defined as part of the concept. The basic procedure is the issuance of an additional clearance from the controller to the ATAAS-equipped aircraft flight crew, which identifies the traffic to follow and the assigned time interval for spacing. Once the flight crew accepts the spacing clearance and begins following the ATAAS-commanded speeds, no further speed clearances are needed from Air Traffic Control (ATC), but other normal communications (frequency changes, approach and landing clearances) take place as usual.

Flight crew procedures were developed to allow interaction with the ATAAS tool, with minimal impact to current workload levels. Supporting display elements were developed to provide information to the crew on the ATAAS mode and the current state of the ATAAS-equipped aircraft ("ownship") relative to the aircraft it is spacing behind (the "lead" aircraft). A simple pilot interface with the ATAAS tool allows the crew to select the lead aircraft and enter other appropriate data required for optimizing the ATAAS tool's performance.

The ATAAS algorithm is designed to provide pilots with speed commands which, when properly followed, will result in the target spacing interval behind the lead aircraft at the runway threshold. The aircraft speed can be controlled to follow the ATAAS command speed automatically (by engaging the tool directly connected to the autothrust system) or with the pilot following the displayed command speed cues by making appropriate inputs to either the throttle levers or by dialing in the command speed in the Mode Control Panel (MCP) speed window. These three methods of speed control are referred to in this study as Automatic, Manual, and MCP, respectively. The speed command provided by the ATAAS system does not differ in any way for any of the methods of speed control used.

3.0 ATAAS Test

3.1 Facilities

The facility used for this experiment was the NASA LaRC Integration Flight Deck (IFD) simulator (Figure 1). The IFD simulator cab is an engineering cab designed to represent the conventional flight deck of the NASA ARIES (Airborne Research Integrated Experiments System) B-757 airplane. The cab is populated with flight instrumentation, including the overhead subsystems panels, to replicate the B-757. The cockpit contains a “Panorama” visual out-the-window display system. This system provides a 200 degree by 40 degree visual out-the-window display to add realism to piloted experiments.

Figure 1. NASA LaRC Integration Flight Deck Simulator

During these simulation tests, significant cockpit modifications included a non-standard control panel for the Navigation Display (ND), the addition of a page to the Flight Management Computer (FMC) Control-Display Unit (CDU), and minor format modifications to the Electronic Attitude Director Indicator (EADI). This non-standard ND control panel was located on the aisle stand just aft of the throttles. The ND control panel contained a push-switch that was used to activate the ATAAS system.

ATC communications were provided to the IFD during the experiment from a station located remotely from the simulator cab. The station had a display of air traffic and other information so that a single pseudo-controller could provide the real-time communications with other simulated traffic and the IFD cab. Pilots’ headsets were used in the simulator cab to simulate radio communications.

Pilots obtained ATAAS speed commands from the EADI and ND displays and the command airspeed bug on the airspeed indicator. Additional ATAAS status data and crew inputs were provided on various Flight Management Computer (FMC) Control/Display Unit (CDU) pages. The ATAAS symbology on the EADI and ND appeared only after a lead aircraft and spacing interval were selected from the CDU page.

3.2 Test Scenario

A single subject pilot was used for data collection, with a confederate pilot (member of experiment team) in the right seat. The confederate pilot was a retired airline pilot from a major air carrier, with experience as a participant in research studies at LaRC. Since crew interactions were not a focus of this study, this crew arrangement provided the opportunity to obtain data on acceptability and workload from the subject pilot while still maintaining the realism of operating in a two-person crew, full-mission environment.

The simulated environment for this study was the Memphis International Airport (MEM) and surrounding terminal area. Calm wind conditions and visibility of 10 miles in haze was simulated. The traffic level corresponded to what might be expected at a busy terminal area. Normal ATC radio communications were provided through a simulated ATC facility. Other traffic in the pattern, using pre-recorded tracks of arriving aircraft, were shown on the ownship displays and the out-the-window computer-generated imagery system. The same flight scenario was used for all runs, and began with the subject aircraft level at 8000 ft, 250 kts indicated airspeed, approximately 10 nmi prior to the downwind turn.

3.3 Test schedule

Eight different pilots participated in this experiment. Each pilot was scheduled to complete all briefing, training, and testing in one day. A test matrix of eight data runs (Table 1) was completed by each pilot, with each data run lasting approximately 20 minutes. A Latin Square design was used to order the runs (Table 2), to minimize potential interactions of the test variables. The eye-tracker was re-calibrated after each run.

Table 1. Test Matrix

Subject Role→	Pilot Flying	Pilot Not Flying
Baseline	1	5
Manual Throttle	2	6
MCP speed	3	7
Automatic	4	8

Table 2. Ordering of runs for all pilots.

Condition Number	Pilot 1 order	Pilot 2 order	Pilot 3 order	Pilot 4 order	Pilot 5 order	Pilot 6 order	Pilot 7 order	Pilot 8 order
1	1	6	8	3	7	5	2	4
2	5	2	4	1	6	8	3	7
3	2	4	1	6	8	3	7	5
4	3	7	5	2	4	1	6	8
5	6	8	3	7	5	2	4	1
6	8	3	7	5	2	4	1	6
7	4	1	6	8	3	7	5	2
8	7	5	2	4	1	6	8	3

The subject pilot was briefed on the crew procedures, to supplement a copy of the flight manual bulletin and charts which were developed for the study and previously mailed to the subject pilot. Included in the bulletin was background information on the operation and the charted procedure, a summary of the procedures for interacting with the custom ATAAS FMC-CDU pages, and a checklist indicating the crewmember responsibilities. The Pilot Not Flying (PNF) was responsible for making inputs to the flight management system through the CDU. This included selecting the assigned traffic to follow, entering the assigned spacing interval and any other necessary data (such as final approach speeds) on the ATAAS CDU pages. The PNF also acknowledged the clearance with ATC. The Pilot Flying (PF) was responsible for activating the ATAAS system and following the speed commands. Both pilots were responsible for monitoring of speed and other cues to ensure compliance with the speed commands. However, during this test, the confederate pilot did not advise the subject pilot when to adjust speed. These tasks were to be integrated with other normal duties. Each subject pilot acted as PF in half the runs he completed, and PNF in the other half.

The autopilot was engaged during all test runs. The autothrottles were engaged on all test runs except those where manual throttle operations were required. All the ATAAS runs consisted of complete FMS routes that were flown in the LNAV mode for lateral guidance. The baseline runs were flown as they are currently flown in real-world operations, with LNAV for lateral guidance until the end of the STAR, and then transitioning to the HEADING SELECT mode to comply with vectors from ATC.

3.4 Subject pilots

Subject pilots were required to be type-rated and current in the B757 aircraft. Total flight time for each pilot ranged between 4000 and 17000 hours. Two pilots had between 300-1000 hours in type, and the remainder had over 1000 hours in type. There were five first officers and three captains, from a total of four different airlines.

4.0 Eyetracker results

An eyetracker was used to record the subject pilots' eye movements, to ascertain that the introduction of the ATAAS tool on the flight deck was not detrimental to the pilots' out-the-window scan. It was noted during the data collection that all the pilots made attempts to see the other traffic, since the other traffic aircraft were visible out the window. The eye movement results of this study address issues related to the effect of ATAAS on pilot visual attention, and can offer objective support for pilot judgments of ATAAS acceptability under the varying levels of automation.

4.1 Data Analysis

Pilot gaze and eye movement data were recorded using an eyetracker (ISCAN Model AA-ETL-500 low-level infrared, eye-tracking system and supporting software). The eyetracker weighed less than 8 oz. and was mounted on a baseball cap. The wiring was bundled with the pilot's headset so that it did not interfere with a normal range of pilot head movement. Samples were obtained at 30 Hz. Fixations having a minimum duration of 100 ms within a one-inch square area were recorded. Eyetracker data were recorded on videotapes and through the eyetracker data collection software.

The dwell or duration of fixations was defined as the time between entering and exiting an Area of Interest (AOI). The following AOIs were defined, as shown in Figure 2: 1) EADI, 2) ND, 3) Airspeed Indicator, 4) Altimeter, 5) MCP, 6) Window, 7) Left side CDU, 8) instruments on the right side, and 9)

Right side CDU. The defined areas of interest (AOIs) accounted for 85% of all recorded fixations. Prior to analysis data were segmented through review of the eyetracker videotapes into sets labeled "Downwind" and "Final Approach". The Downwind segment comprised the period from the start of the run to completion of the turn onto the base leg of the arrival pattern (but not including the full base leg). Final Approach started with transmission of the Final Approach clearance as the aircraft began to turn onto the Final Approach leg, and concluded with touch down.

Figure 2. Definition of Eyetracker Areas of Interest (AOIs)

4.1.1 Pilot Scan Pattern

The effect of ATAAS on pilots' visual scan patterns was examined through a link analysis (results are shown in Appendix A). This is a method of assessing the pattern of how a person's gaze transitions from one area of interest to another, such as from the EADI to the airspeed indicator. The link analysis was conducted separately on the Downwind and Final Approach data sets. Comparisons were made between the ATAAS and Baseline conditions, and among the ATAAS conditions, to examine the effect of ATAAS in conjunction with the different methods of speed control. Link values represent the percentage of unidirectional eye movements between defined AOIs (i.e., movement from one AOI to another). Where results are cited without specifying the Downwind or Final Approach data set, the same result was found in both.

Overall, the pilots' scans did not appear to exhibit a definable sequence of eye movements from one AOI to another, since the link values were nearly equivalent in either direction. This was equally true of both ATAAS and baseline conditions. The strongest link in nearly all conditions was from EADI to Airspeed, which was higher in all ATAAS conditions than in the comparable (PF or PNF) baseline condition in both the Downwind and Final Approach flight segments. However, the increase was only by one or two percent. This was expected, since the additional task required with the use of ATAAS is to follow the airspeed. The only exception was in the PF Manual conditions, where the EADI-to-Airspeed links accounted for nearly 16% of the eye movements in comparison with the 10% (Downwind) and 11% (Final Approach) link values for the PF Baseline conditions. Similarly, most of the reverse link values (from Airspeed to EADI) were higher by three percent or less in the ATAAS conditions than in the comparable baseline conditions. The exception was again PF Manual, where the Airspeed-to-EADI link was 14% for Downwind and 15% for Final Approach, compared to PF Baseline values of 8% for both Downwind and Final Approach. The link values for PF Auto and PF MCP differed by less than two percent, as did those for PNF Auto and PNF MCP. The introduction of ATAAS did not result in any unusual eye movements between instruments different from the Baseline condtion.

The ND to EADI links were stronger in PF MCP (11%) and PF Auto (10%) than in PF Baseline (7% for Downwind and 8% for Final Approach), but weaker in PF Manual (5%). Very similar results were found in the opposite direction EADI to ND links, which varied from the ND to EADI results by no more than one percent.

A higher percentage of eye movements toward Window were found in PF Auto (10%) and PF Baseline (9% during Downwind, 10% during Final Approach) than were found in PF MCP (6% during Downwind, 7% during Final Approach) or PF Manual (5%). The EADI to Window link was the strongest with values of 3% to 4% in all but the PF and PNF Manual conditions during Downwind, and 4% to 5% in all but the PF and PNF Manual conditions during Final Approach. The link values for PF and PNF Manual were one to two percent less than the comparable baseline during Downwind and Final Approach.

4.1.2 Allocation of Visual Attention

The pilots' allocation of visual attention is inferred from the proportional distribution of dwell time, which is the proportion of the run time in each flight segment (Downwind or Final Approach) that the pilot's gaze remained within an AOI. This analysis examined each of the AOIs to determine whether the test conditions (Condition), differences among the pilots (Subject), or ordinal position of the simulation run (Run) produced statistically significant differences in the proportional distribution of dwell time.

The proportions of visual attention allocated to AOIs during the Downwind flight segment are shown in Figures 3 and 4 for the PF and PNF conditions, respectively. The proportions of visual attention allocated to AOIs during the Final Approach segment are shown in Figures 5 and 6 for the PF and PNF conditions, respectively. The means and standard deviations of these proportions can be found in Appendix B. An 8 X 8 within subjects Analysis of Variance (ANOVA) was conducted on percent dwell time by Condition, Subject, and Run for each of the seven AOIs. Separate ANOVAs were conducted on the Downwind and Final Approach data sets. For all analyses reported below, a significance level of $\alpha = 0.05$ was used and significant main effects were further analyzed with Tukey (Type A) post hoc tests[5].

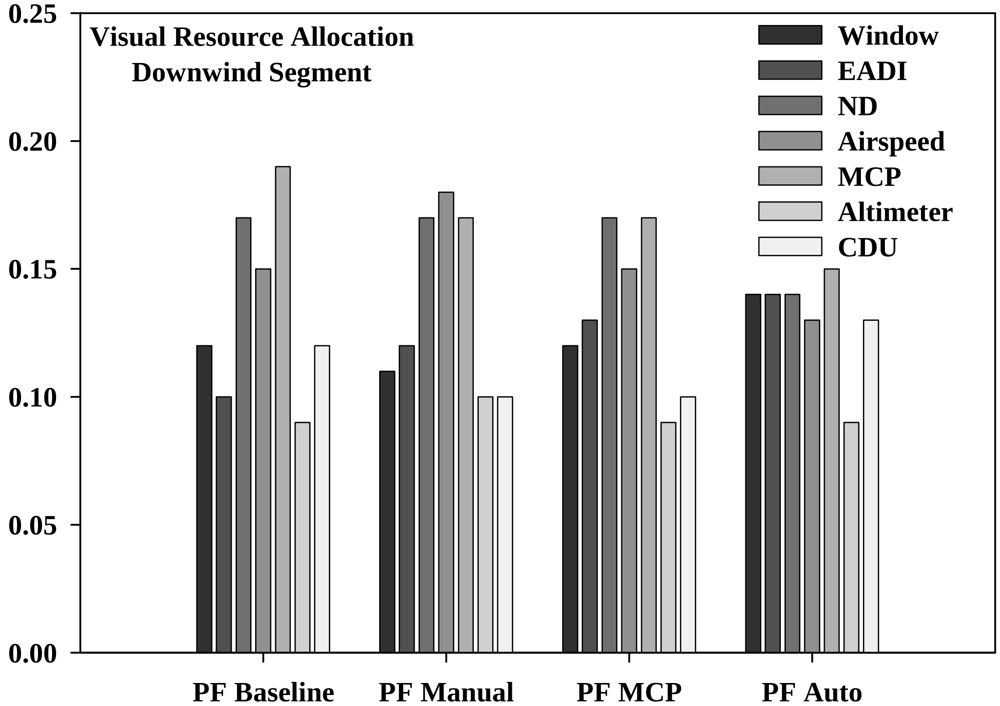

Figure 3. Visual resource allocation in the Pilot Flying conditions during Downwind.

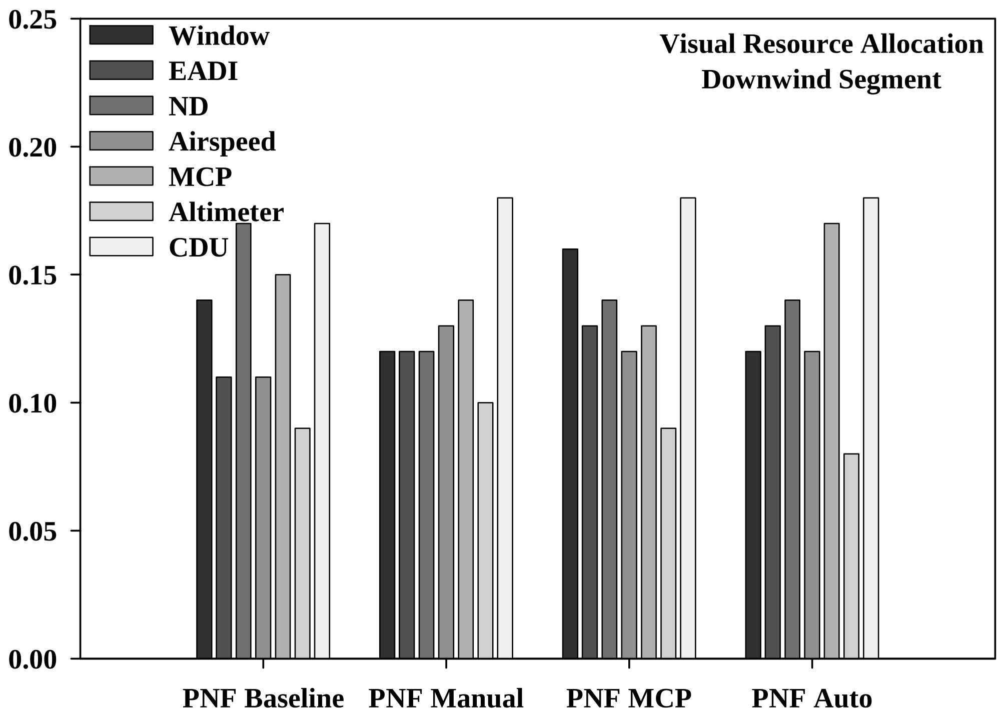

Figure 4. Visual resource allocation in the Pilot Not Flying conditions during Downwind.

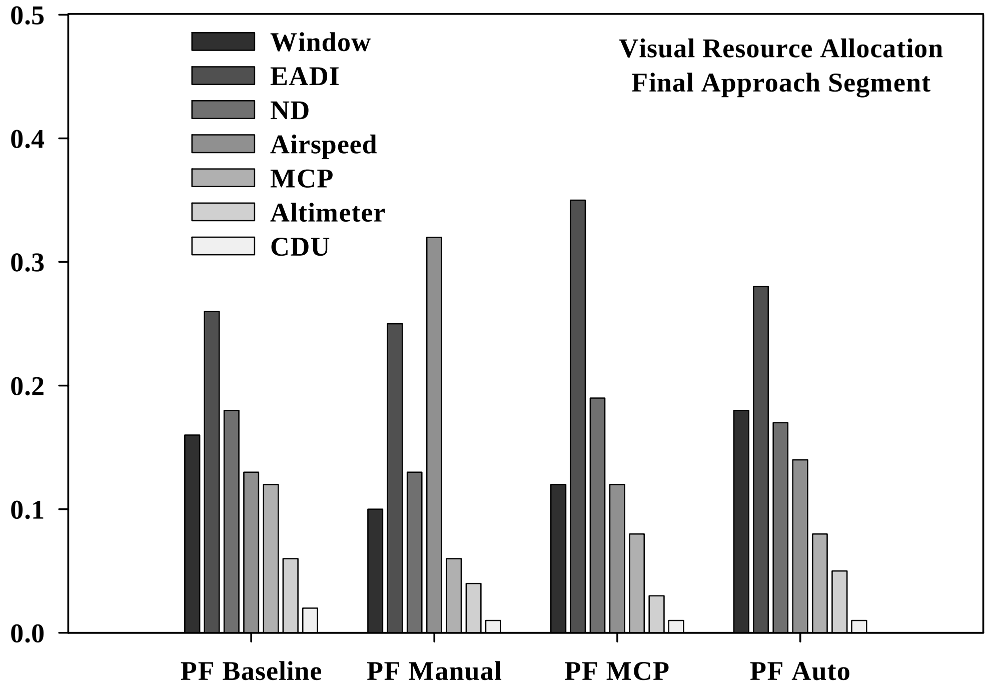

Figure 5. Visual resource allocation in the Pilot Flying conditions during Final Approach.

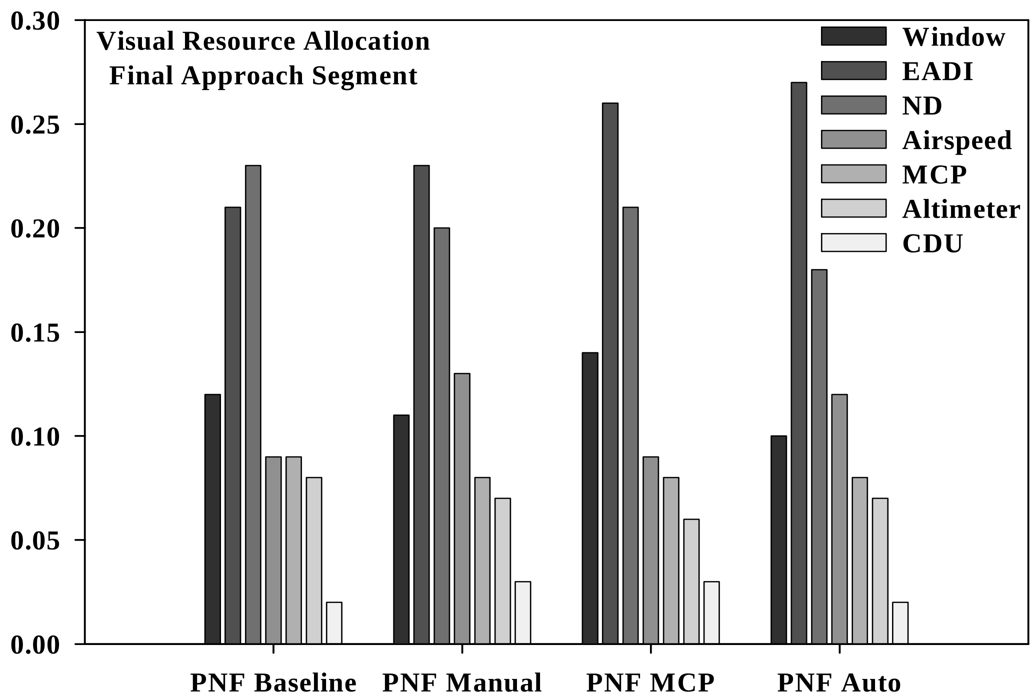

Figure 6. Visual resource allocation in the Pilot Not Flying conditions during Final Approach

In the data from the Downwind flight segment, the ANOVA on EADI found significant effects of Condition, F (7, 42) = 2.26, p = 0.048 and Subject, F (7, 42) = 6.72, p < 0.0001. Multiple comparisons indicated that the attentional allocation to EADI in PF Auto (14%) was significantly higher than in PF Baseline (11%). The ANOVA conducted on ND found significant effects of Condition, F (7, 42) = 2.71, p = 0.021 and Subject, F (7, 42) = 5.87, p < 0.0001. Multiple comparisons on Condition found no significant differences. The ANOVA on Condition for Airspeed was significant F (7, 42) = 8.28, p < 0.0001. Multiple comparisons indicated that the Airspeed allocation in PF Manual (18%) was significantly higher than in any other condition (range: 11% to 15%). The ANOVA on Left CDU found a significant effect of Condition F (7, 37) = 4.06, p = 0.002. The Left CDU allocation in PNF Auto (18%) was significantly higher than in PF MCP or PF Manual (both 10%). Also, the allocation in PNF Manual (18%) was significantly higher than in PF MCP or PF Manual.

The ANOVA conducted on EADI allocations during Final Approach found significant effects of Condition, F (7, 42) = 2.76, p = 0.003 and Subject, F (7, 42) = 3.69, p = 0.003. Multiple comparisons indicated that the attentional allocation for EADI during PF MCP (35%) was significantly higher than during the PNF Manual (23%) and PNF Baseline (21%) conditions. The ANOVA conducted on ND found an effect of Condition that approached significance F (7, 42) = 2.07, p = 0.068 and an effect of Subject, F (7, 42) = 9.58, p < 0.0001. Significantly more attention was devoted to ND in the PNF Baseline condition (23%) than in PF Manual (13%). The ANOVA on Condition for Airspeed was significant, F (7, 42) = 14.43, p < 0.0001. The PF Manual allocation to Airspeed (33%) was significantly higher than the allocation that was found in any of the other conditions (range: 9% to 14%).

The proportion of dwell allocated to the Altimeter showed significant differences for Condition, F (7, 40) = 4.10, p = 0.0018 and Subject, F (7,42) = 6.25, p < 0.0001. In particular, the allocation to Altimeter in the PNF Baseline (8%) was significantly higher than in the PF Auto (5%), PF Manual (4%), and PF MCP (3%) conditions. Also, the Altimeter allocation was higher in the PNF Manual (7%) condition than in PF MCP. The ANOVA on the MCP allocations resulted in significant differences for Condition, F (7, 42) = 4.40, p = 0.0010, Subject, F (7,42) = 7.38, p < 0.0001, and Run, F (7, 42) = 2.75, p = 0.0193. The PF Baseline MCP allocation (12%) was significantly higher than that for any of the other conditions (range: 6% to 8%) except PNF Baseline. Multiple comparisons on Run failed to find any significant differences. The ANOVA on Window showed significant differences for Condition, F (7, 42) = 3.07, p = 0.0105 and Subject, F (7, 14) = 16.78, p < 0.0001. The amount of attention given to Window was significantly higher in PF Auto (18%) than in PF Manual (10%) or PNF Auto (10%). The ANOVA on Left CDU found a significant effect of Condition, F (7, 42) = 6.55, p < 0.0001 and Subject, F (7, 42) = 2.75, p = 0.019. The allocation to Left CDU in PNF Auto (4%) was significantly higher than in PF Baseline (2%), PF Manual (1%), PF Auto (1%), or PF MCP (1%). Also, significantly more attention was devoted to Left CDU in PNF MCP (3 %) and to PNF Manual (3%) than to PF Auto or PF MCP. This is to be expected, since the pilot has more time to look out the window when he did not have to manually control the speed.

4.1.3 Dwell Time

Dwell time is the length of time that the pilot's gaze remained within an AOI without moving outside of that area. The analysis performed on dwell time was the same as in the preceding section for allocation. The values for mean and standard deviation of these dwell durations can be found in Appendix B.

The mean dwell duration was obtained for each pilot and subjected to analysis. The means of these dwell values for the PF and PNF conditions are shown in Figures 7 and 8 for the Downwind flight segment and in Figures 9 and 10 for Final Approach.

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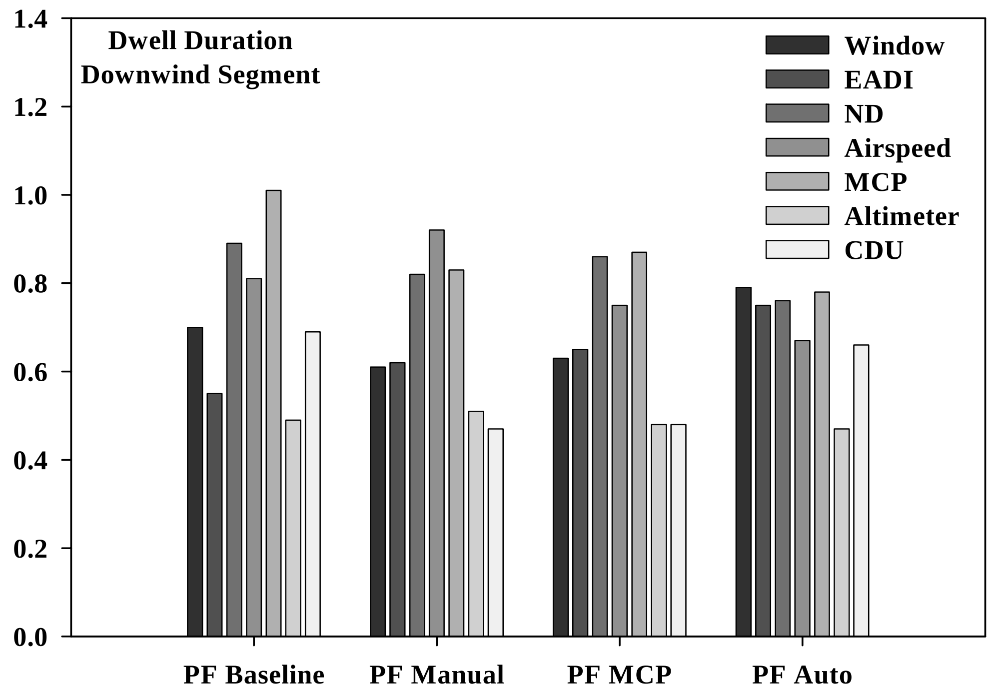

Figure 7. Mean dwell duration in the Pilot Flying conditions during Downwind.

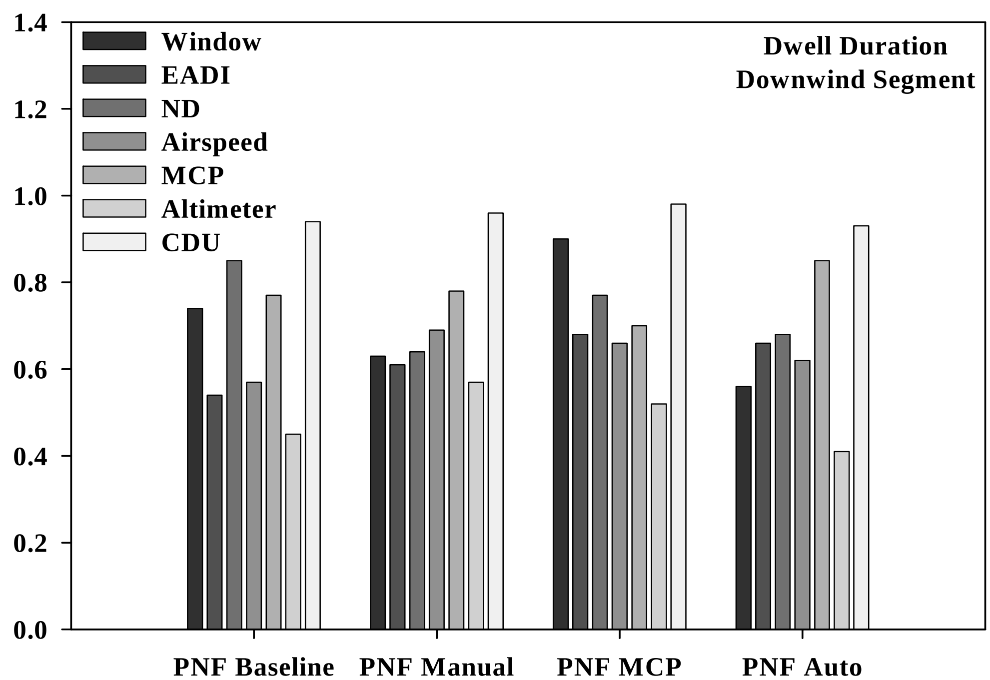

Figure 8. Mean dwell duration in the Pilot Not Flying conditions during Downwind.

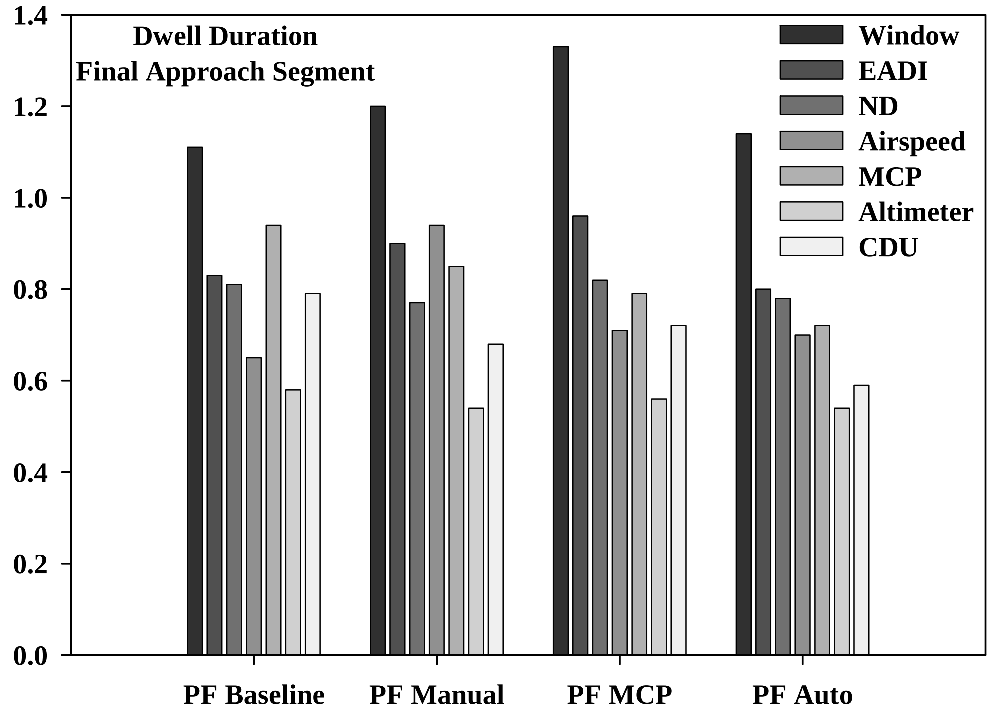

Figure 9. Mean dwell duration in the Pilot Flying conditions during Final Approach

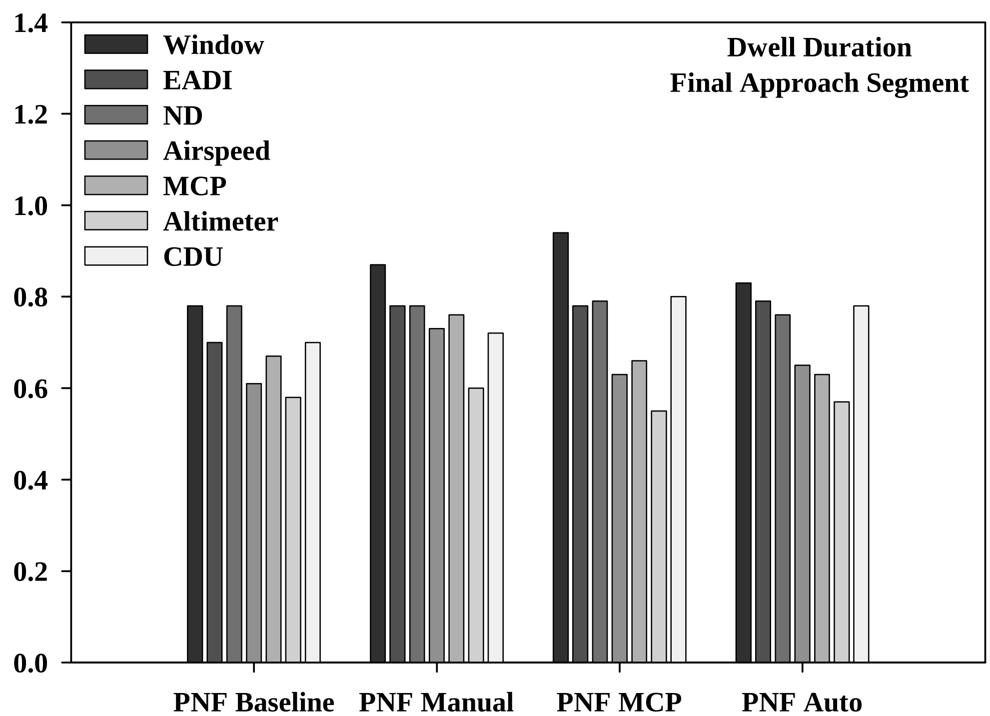

Figure 10. Mean dwell duration in the Pilot Not Flying conditions during Final Approach.

Separate analyses were conducted on the Downwind and Final Approach data sets. For each data set, an 8 X 8 within subjects ANOVA was conducted on mean dwell time by Condition, Subject, and Run for each of the seven AOIs. Significant effects were followed by multiple comparisons using the Tukey HSD Test, $p < 0.05$.

The ANOVA on the EADI mean durations in the Downwind data set found a significant effect of Subject, F (7, 42) = 3.62, p. = 004. A significant effect of Subject was also found in the ANOVA on ND, F (7, 42) = 5.32, $p = 0.0002$. The analysis of Airspeed showed a significant effect of Subject, F (7, 42) = 5.65, $p <$ 0.0001 and Condition F (7, 42) = 3.11, $p = 0.0098$. The mean dwell on Airspeed in PF Manual (0.92 seconds) was significantly longer than in PNF Baseline (.62 seconds) and PNF Auto (.57 seconds). The ANOVA on Altimeter found a significant effect of Subject F (7, 40) = 7.71, $p < 0.0001$, as did the ANOVA on Window, F (7, 33= 2.61, $p = 0.029$. For Left CDU, the analysis found a significant effect of Condition F (7, 37 = 3.51, $p = 0.029$. However, multiple comparisons failed to find any significant differences between pairs of conditions.

In the Final Approach data set, a significant effect of Subject was found in the analysis of mean dwell time for ND, F (7, 42) = 3.29, $p = 0.007$. The ANOVA on Airspeed found significant effects of Condition, F (7, 42) = 8.28, $p < 0.0001$ and Subject, F (7, 42) = 8.28, $p < 0.0001$. For Airspeed, the mean dwell duration in PF Manual (.94 seconds) was significantly longer than that of any of the other conditions (range: 0.61 seconds to 0.73 seconds). The analysis of Altimeter found a significant effect of Subject, F (7, 40) = 2.32, $p < 0.0001$and Run, F (7, 40) = 2.32, $p = 0.0438$. However, multiple comparisons failed to find any significant differences for Run. The ANOVA on MCP found a significant effect of Condition, F (7, 42) = 2.64, $p = 0.0236$. The mean dwell for MCP in the PF Baseline condition (.94 seconds) was significantly longer than in the PNF Auto condition (.63 seconds). The ANOVA on Window found significant effects of Condition, F (7, 42) = 4.11, $p = 0.0016$ and Subject, F (7, 42) = 2.71, $p = 0.02$. The mean dwell for Window in PF MCP (1.33 seconds) was significantly longer than in these conditions: PNF Manual (.87 seconds), PNF Auto (.83 seconds), and PNF Baseline (.79 seconds). The analysis of the CDU mean dwell times found a significant effect of Subject, F (7, 42) = 3.74, $p = 0.003$.

As expected, the mean dwell time for pilots looking out the window was greater on the final approach segment than on downwind whether or not ATAAS was used, although there were overlaps in the standard deviations among the different conditions. Comparing the Baseline condition with each of the three ATAAS conditions for the two segments shows some expected variations in mean dwell duration values. For the downwind segment, the Manual and MCP conditions showed lower mean dwell times than the Baseline condition, and Automatic showed higher mean dwell times, meaning that the pilots had less time to dwell on looking out the window during the Manual and MCP conditions than the Baseline condition, and more time during the Automatic condition than the Baseline condition. However, on final approach dwell times were longer for the Manual and MCP conditions than for Baseline, and slightly higher for the Automatic condition versus Baseline. The dwell times for the Automatic condition are very similar to the Baseline condition, with slightly higher variation. The higher standard deviations for the Manual and MCP conditions on final approach indicates more variation among the pilots, and further studies dedicated to and designed around obtaining eyetracker data could provide more insight

4.1.4 Individual Differences

Individual differences occurred in how pilots allocated their attention to EADI and ND, both of which provided speed cues, and to Window. Appendix B shows the mean proportional allocation of visual attention to these three areas of interest for all the data runs. Some uniformity can be seen in the ATAAS conditions: One group of subjects allocated more attention to EADI: these five pilots (2, 3, 4, 7, and 8) distributed their attention about equally (within 3%) between the EADI and ND displays in the Downwind flight segment and paid more attention to the EADI than to the ND in the Final Approach segment. The remaining three pilots (1, 5, and 6) emphasized ND: they allocated more attention to ND than EADI during Downwind, and paid about equal amounts of attention to the two displays during the Final Approach segment. This pattern of results is not found in the baseline conditions.

Since Pilot 6 indicated in the post-run questionnaires that head down time was somewhat unacceptable or marginally acceptable during the ATAAS conditions in the Downwind segment, his eyetracker results were examined to investigate the reason for these ratings. These eyetracker data included relatively high frequencies and long fixations on the ND. Differences in proportional allocation for all pilots are shown in Table 3 (for each of the three AOIs in the table, the left column contains the means for the six ATAAS conditions, and the shaded right column contains the means for the two baseline conditions). Frequency and mean dwell time for fixations on the ND are shown in Table 4 for Pilot 6 along with the results of Pilots 1 and 5, who also emphasized ND relative to EADI, but who indicated that head down time was very acceptable during the Downwind segment. Results shown were obtained from the Downwind flight segment. Pilots 1 and 5 rated head down time as very acceptable (6 or 7 on the 7-point scale), while Pilot 6 rated head-down time as low to marginally acceptable (2 to 4 on the 7-point scale). The rating for the PNF Manual condition was missing, and ratings for the baseline conditions were not collected. The difference appears to be that in the PF conditions Pilot 6 normally takes relatively few, quick glances at the ND, as seen in the PF Baseline condition results. His fixations on the ND in the PF MCP and PF Auto conditions were more numerous and longer in duration than in the PF Baseline condition.

Table 3. Individual differences in proportional allocation of visual attention.

	Downwind						Final Approach					
Pilot	EADI		ND		Window		EADI		ND		Window	
1	.13	.11	.19	.23	.08	.11	.32	.22	.30	.33	.05	.07
2	.17	.18	.14	.21	.13	.16	.19	.12	.14	.20	.25	.30
3	.11	.10	.14	.17	.15	.13	.27	.27	.14	.16	.15	.14
4	.14	.10	.11	.11	.13	.12	.30	.23	.13	.14	.11	.07
5	.10	.09	.16	.18	.12	.16	.23	.21	.21	.19	.13	.13
6	.13	.08	.18	.15	.13	.12	.25	.32	.24	.16	.12	.14
7	.13	.09	.11	.14	.15	.13	.30	.23	.09	.20	.15	.17
8	.13	.10	.13	.16	.11	.13	.33	.30	.17	.24	.06	.05

Table 4. Frequency and mean dwell time for fixations on the ND.

	Pilot 1		Pilot 5		Pilot 6	
Condition	Frequency	Dwell	Frequency	Dwell	Frequency	Dwell
PF Baseline	94	1.05	67	1.32	68	.55
PF MCP	95	.87	50	.78	95	1.02
PF Auto	103	.78	66	1.16	92	1.05
PF Manual	61	.75	34	1.13	68	.71
PNF Baseline	102	.80	60	1.20	73	.94
PNF MCP	109	.87	46	1.39	93	.78
PNF Auto	96	.93	39	1.03	91	.61
PNF Manual	60	.56	27	.99	56	.57

4.1.5 Pilot Visual Response to ATAAS Speed Change

When ATAAS produced a speed change, the new speed was shown on both the EADI and ND. Both displays also flashed for several seconds to attract the pilots' attention to a change in commanded speed. The time pilots took to first look at either display following a speed change was examined for the PF

MCP and PF Manual conditions. In these two conditions, the pilot needed to take an action based on the visually presented information whereas no action was required in the PF Auto condition, and speed changes were communicated aurally in the PF Baseline condition.

Figure 11 shows the percentages of response times of varying length obtained under the PF MCP and PF Manual conditions. For PF MCP, 91% of the responses occurred in less than 10 seconds. For PF Manual, 73% occurred in less than 10 seconds. The maximum response time in PF MCP was 22.4 seconds, and in PF Manual the maximum response time was 37.3 seconds. For PF MCP, the median response time was 1.9 seconds, and for PF Manual the median was 3.8 seconds. Additionally, no visual response was made before the onset of the next speed change on three occasions in PF MCP and twice in PF manual.

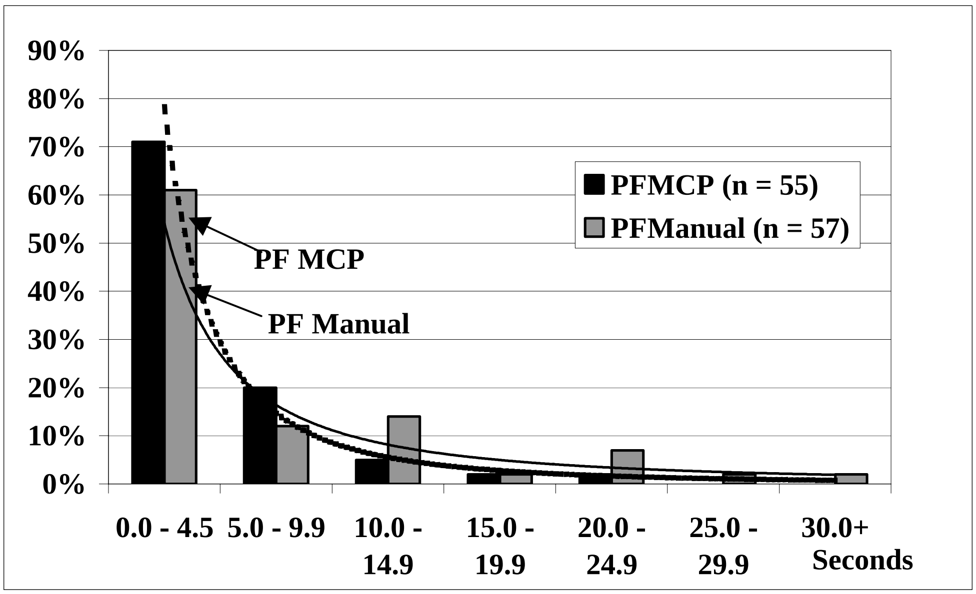

Figure 11. Pilot Visual Response to ATAAS Speed Change.

Thus, 94% of the commanded speed changes in PF MCP and 96% in PF Manual elicited a visual response prior to the next speed change. A regression analysis was performed on the data shown in Figure 11. The regression equation for PF MCP was $Y = 0.78X^{-2.41}$ ($R^2 = 0.97$), and for PF Manual it was $Y = 0.54X^{-1.72}$ ($R^2 = 0.82$).

4.2 Discussion

Eye movement data can yield useful, objective information regarding the head-down demands of new flight deck displays. Since the ATAAS tool is intended for use during a typically high workload phase of flight when out-the-window attention to the runway is required, the head-down demands of using the ATAAS tool under varying levels of automation can be of interest. Both the pilot flying and the pilot not flying should find the head-down demands of the ATAAS tool to be acceptable before its design is finalized. The eye movement results of this study can offer objective support for their judgments of ATAAS acceptability under varying levels of automation. In post-test questionnaires, pilots rated the head-down time required for using the ATAAS tool higher than that required for a standard procedure. However, they also rated highly the acceptability of the additional head-down time[4].

The eye movement results of this study address issues related to the effect of ATAAS on pilot visual attention. The effects of the ATAAS speed commands can be seen in comparisons between the MCP and Baseline conditions because speed changes were made by the pilot dialing the desired speed into the MCP speed window. Other comparisons to the baseline conditions are confounded with differences in automation (or the lack thereof). For example, effects seen in comparisons between Manual and Baseline could be attributed to ATAAS, differences between manual throttle speed control and MCP speed control, or both.

Few differences in visual attention were found that can clearly be attributed to ATAAS. The only statistically significant effect was that the percentage allocation of attention to the MCP was significantly greater (by 4%) in PF MCP than in PF Baseline during the Final Approach flight segment. This was most likely due to a greater number of speed changes during this segment on ATAAS runs versus baseline runs. No significant differences in dwell time were found in comparisons between the PF MCP or PNF MCP and the comparable baseline conditions in either the Downwind or Final Approach data sets, indicating that the pilots' scans were not changed significantly by the addition of the ATAAS tool. Also, few differences in pilot scan patterns were evident. The largest differences between the PF MCP or PNF MCP and baseline conditions occurred in eye movements from ND and Airspeed to EADI. Both links showed a small increase that can be attributed to ATAAS – 2% for Airspeed and 3% for ND in both the Downwind and Final Approach results. Small decreases in eye movements from all instruments to the Window can also be attributed to ATAAS (indicating that fewer time was available to spend looking out the window), but none of the individual links decreased by more than one percent. In all, ATAAS reduced eye movements to the Window by 3% during Downwind and by 2% during Final Approach.

The eye movement results for the PF Manual condition were strongly affected by the need to attend to Airspeed. During Downwind, the pilots allocated 18% of their visual attention to Airspeed, significantly more than in any other condition. During Final Approach, this allocation increased to 33%, where it was more than twice the amount found in any other condition. PF Manual also produced a significantly longer dwell on Airspeed during Final Approach than any other condition.

The relatively high attentional demand for Airspeed in PF Manual may have caused tradeoffs in attention to other areas of interest. The link analysis found that the ND to EADI link was stronger in PF Auto and PF MCP than in PF Baseline, but this link in PF Manual was weaker than in PF Baseline. The allocation of attention to Window was significantly lower in PF Manual (10%) than in PF Auto (18%). It should be noted that these effects could simply be the result of pilots having to pay more attention to manual throttle inputs to control speed, resulting in less time to look out the windows. This might have no connection to ATAAS, and pilots who normally use a manual throttle may not allocate as much attention to the airspeed indicator as the pilots who participated in this study.

An analysis was performed on the pilot visual response following the commanded speed changes in the PF MCP and PF Manual conditions. The median time to look at one of the two displays (ND or EADI) showing the new commanded speed was 1.9 seconds in PF MCP and 3.8 seconds in PF Manual. The longer response time in PF Manual is an indication of higher workload in that condition. Although a sizable majority of the response times in both of these conditions occurred in less than 10 seconds, 9% in PF MCP and 27% in PF Manual were longer. Also, a few commanded speed changes in each condition did not elicit a visual response before ATAAS commanded the next speed change. The spacing results that were found in this study were achieved despite this variability in the time it took the pilots to look at the display bearing the new commanded speed. However, this study was not designed to examine the relationship between pilot response and ATAAS spacing outcomes. A separate study would be needed to identify the limits of pilot response that the ATAAS system can tolerate and still achieve acceptable spacing results.

5.0 Concluding Remarks

A concept for providing airborne-managed in-trail spacing in the terminal area was developed, and subsequently evaluated in a full-workload simulator with airline subject pilots. This concept included procedures for flight crew interaction with air traffic controllers as well as with the onboard algorithm that provides speed commands for achieving the target spacing. Three methods of speed control were evaluated through comparison with a baseline case in which current-day procedures were used.

Although pilots indicated that the head-down time was slightly higher when using the ATAAS tool, eyetracker data showed only slight changes in instrument scan patterns, and no significant change in the amount of time spent looking out the window with ATAAS, versus standard ILS procedures. The eyetracker data showed that the amount of time spent looking out the window was not significantly changed when pilots used the ATAAS procedure versus the nominal ILS procedure.

6.0 References

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[3] Abbott, Terence S., “Speed Control Law For Precision Terminal Area In-Trail Self-Spacing," NASA/TM-2002-211742, July 2002.

[4] Oseguera-Lohr, Rosa M., Gary W. Lohr, Terence S. Abbott, and Todd M. Eischeid, “Evaluation of Operational Procedures for Using a Time-Based Airborne Inter-Arrival Spacing Tool,”AIAA Paper 2002-5824, October, 2002.

[5] Tukey, J. W., “The Problem of Multiple Comparisons,” Ditto, Princeton University, 1953.

Appendix A
Link Analysis

Downwind Segment

	From/To	EADI	ND	Air Spd	Altitude	MCP	Window	CDU
PF Base	EADI	0.00%	6.80%	10.39%	4.96%	1.72%	3.75%	0.23%
	ND	7.20%	0.00%	6.33%	2.31%	2.52%	1.63%	0.58%
	Air Speed	7.76%	7.29%	0.00%	2.52%	1.82%	2.00%	0.23%
	Altitude	4.98%	2.03%	2.56%	0.00%	0.93%	0.65%	0.07%
	MCP	2.42%	2.59%	1.47%	0.33%	0.00%	1.21%	0.23%
	Window	4.96%	1.14%	0.95%	0.56%	1.28%	0.00%	0.16%
	CDU	0.35%	0.68%	0.12%	0.09%	0.07%	0.14%	0.00%
	From/To	EADI	ND	Air Spd	Altitude	MCP	Window	CDU
PF MCP	EADI	0.00%	10.27%	11.64%	4.15%	3.09%	3.07%	0.60%
	ND	10.66%	0.00%	5.98%	1.40%	2.70%	0.89%	1.03%
	Air Speed	10.02%	6.92%	0.00%	1.15%	1.21%	1.21%	0.11%
	Altitude	4.15%	1.47%	1.01%	0.00%	0.44%	0.41%	0.09%
	MCP	3.09%	2.77%	1.01%	0.07%	0.00%	0.83%	0.25%
	Window	3.23%	0.80%	0.64%	0.57%	1.01%	0.00%	0.07%
	CDU	0.85%	0.76%	0.18%	0.02%	0.11%	0.05%	0.00%
	From/To	EADI	ND	Air Spd	Altitude	MCP	Window	CDU
PF Manual	EADI	0.00%	5.24%	15.67%	3.64%	1.71%	1.93%	0.43%
	ND	5.04%	0.00%	8.66%	1.30%	1.56%	0.51%	0.47%
	Air Speed	14.23%	8.76%	0.00%	3.37%	2.53%	2.02%	0.53%
	Altitude	3.64%	1.42%	3.08%	0.00%	0.53%	0.21%	0.16%
	MCP	1.93%	1.15%	2.78%	0.19%	0.00%	0.47%	0.10%
	Window	2.53%	0.39%	1.40%	0.31%	0.29%	0.00%	0.12%
	CDU	0.80%	0.43%	0.25%	0.08%	0.08%	0.04%	0.00%
	From/To	EADI	ND	Air Spd	Altitude	MCP	Window	CDU
PF Auto	EADI	0.00%	9.04%	11.43%	3.53%	2.25%	3.99%	0.53%
	ND	9.93%	0.00%	5.15%	1.55%	1.69%	1.74%	0.60%
	Air Speed	8.74%	6.40%	0.00%	1.39%	1.95%	1.86%	0.30%
	Altitude	4.06%	1.44%	1.23%	0.00%	0.49%	0.86%	0.23%
	MCP	2.48%	2.32%	1.72%	0.46%	0.00%	1.09%	0.21%
	Window	4.38%	1.62%	1.23%	0.90%	1.32%	0.00%	0.16%
	CDU	0.67%	0.44%	0.14%	0.07%	0.16%	0.23%	0.00%
	From/To	EADI	ND	Air Spd	Altitude	MCP	Window	CDU
PNF Base	EADI	0.00%	7.41%	8.02%	6.11%	1.88%	3.59%	0.50%
	ND	7.80%	0.00%	5.36%	4.67%	2.07%	1.63%	1.82%
	Air Speed	4.98%	6.64%	0.00%	1.91%	0.53%	1.69%	0.11%
	Altitude	6.97%	4.26%	1.49%	0.00%	1.00%	1.00%	0.22%
	MCP	1.99%	2.24%	0.55%	0.69%	0.00%	0.97%	0.50%
	Window	4.06%	1.11%	0.61%	1.08%	0.97%	0.00%	0.25%
	CDU	0.66%	1.80%	0.08%	0.17%	0.41%	0.22%	0.00%
	From/To	EADI	ND	Air Spd	Altitude	MCP	Window	CDU
PNF MCP	EADI	0.00%	9.07%	9.07%	5.75%	2.47%	3.55%	0.61%
	ND	9.09%	0.00%	4.69%	2.86%	1.86%	1.62%	1.27%
	Air Speed	6.68%	4.85%	0.00%	2.23%	0.74%	1.78%	0.50%

	Altitude	5.67%	3.45%	1.38%	0.00%	0.93%	0.64%	0.29%
	MCP	2.36%	1.94%	0.66%	0.48%	0.00%	1.22%	0.42%
	Window	4.45%	1.01%	0.90%	0.66%	1.14%	0.00%	0.27%
	CDU	1.01%	1.43%	0.11%	0.13%	0.37%	0.40%	0.00%
	From/To	EADI	ND	Air Spd	Altitude	MCP	Window	CDU
PNF Manual	EADI	0.00%	7.00%	11.20%	5.53%	2.29%	2.43%	0.79%
	ND	8.31%	0.00%	5.34%	2.59%	1.47%	1.55%	1.66%
	Air Speed	8.47%	6.70%	0.00%	1.69%	0.98%	1.85%	0.54%
	Altitude	5.86%	3.13%	1.69%	0.00%	0.54%	0.57%	0.14%
	MCP	1.80%	2.07%	0.93%	0.33%	0.00%	1.01%	0.60%
	Window	2.81%	1.20%	0.74%	0.76%	1.12%	0.00%	0.30%
	CDU	0.90%	2.07%	0.25%	0.08%	0.46%	0.25%	0.00%
	From/To	EADI	ND	Air Spd	Altitude	MCP	Window	CDU
PNF Auto	EADI	0.00%	7.63%	10.66%	5.45%	1.93%	3.25%	0.64%
	ND	8.83%	0.00%	4.73%	2.82%	1.80%	1.07%	2.07%
	Air Speed	7.79%	5.77%	0.00%	2.07%	0.86%	1.37%	0.43%
	Altitude	5.88%	3.30%	1.29%	0.00%	0.83%	0.51%	0.35%
	MCP	2.20%	1.85%	0.97%	0.40%	0.00%	0.94%	0.51%
	Window	3.49%	0.97%	0.62%	0.78%	1.02%	0.00%	0.38%
	CDU	1.07%	2.26%	0.43%	0.11%	0.21%	0.46%	0.00%

Final Approach Segment

	From/To	EADI	ND	Air Spd	Altitude	MCP	Window	CDU
PF Base	EADI	0.00%	7.15%	11.14%	4.34%	1.65%	4.08%	0.27%
	ND	7.77%	0.00%	5.67%	2.04%	2.16%	1.48%	0.21%
	Air Speed	7.77%	7.48%	0.00%	2.36%	1.33%	2.13%	0.18%
	Altitude	4.79%	1.57%	2.22%	0.00%	0.98%	0.71%	0.00%
	MCP	2.33%	2.19%	1.12%	0.33%	0.00%	1.12%	0.24%
	Window	5.20%	1.00%	1.00%	0.62%	1.33%	0.00%	0.15%
	CDU	0.30%	0.30%	0.09%	0.09%	0.00%	0.12%	0.00%
	From/To	EADI	ND	Air Spd	Altitude	MCP	Window	CDU
PF MCP	EADI	0.00%	10.14%	11.69%	3.46%	3.04%	3.49%	0.55%
	ND	10.66%	0.00%	5.16%	1.06%	2.06%	0.97%	0.85%
	Air Speed	10.05%	6.25%	0.00%	1.00%	0.70%	1.43%	0.09%
	Altitude	3.43%	1.21%	0.82%	0.00%	0.39%	0.49%	0.09%
	MCP	2.91%	2.16%	0.61%	0.09%	0.00%	0.94%	0.24%
	Window	3.92%	0.70%	0.82%	0.64%	1.06%	0.00%	0.09%
	CDU	0.82%	0.46%	0.15%	0.03%	0.12%	0.06%	0.00%
	From/To	EADI	ND	Air Spd	Altitude	MCP	Window	CDU
PF Manual	EADI	0.00%	5.32%	15.76%	3.31%	1.68%	2.36%	0.38%
	ND	5.05%	0.00%	7.72%	1.17%	1.11%	0.49%	0.38%
	Air Speed	14.51%	8.07%	0.00%	3.12%	1.93%	1.85%	0.41%
	Altitude	3.29%	1.14%	2.93%	0.00%	0.43%	0.16%	0.16%
	MCP	1.68%	0.73%	2.34%	0.14%	0.00%	0.41%	0.14%
	Window	2.83%	0.19%	1.55%	0.24%	0.24%	0.00%	0.16%
	CDU	0.79%	0.30%	0.24%	0.08%	0.08%	0.03%	0.00%

	From/To	EADI	ND	Air Spd	Altitude	MCP	Window	CDU
PF Auto	EADI	0.00%	8.54%	11.47%	3.74%	1.54%	4.50%	0.42%
	ND	9.60%	0.00%	4.38%	1.72%	1.12%	1.48%	0.51%
	Air Speed	7.91%	6.31%	0.00%	1.54%	0.91%	2.35%	0.21%
	Altitude	4.41%	1.57%	1.06%	0.00%	0.39%	0.85%	0.24%
	MCP	1.72%	1.24%	0.88%	0.33%	0.00%	0.88%	0.27%
	Window	4.53%	1.54%	1.45%	0.91%	0.97%	0.00%	0.27%
	CDU	0.72%	0.36%	0.15%	0.00%	0.06%	0.30%	0.00%
	From/To	EADI	ND	Air Spd	Altitude	MCP	Window	CDU
PNF Base	EADI	0.00%	6.51%	8.07%	5.65%	1.93%	4.00%	0.45%
	ND	7.34%	0.00%	4.69%	3.72%	1.48%	1.38%	0.83%
	Air Speed	4.69%	6.17%	0.00%	1.79%	0.59%	1.69%	0.10%
	Altitude	6.83%	3.10%	1.45%	0.00%	0.86%	1.00%	0.14%
	MCP	1.90%	1.76%	0.48%	0.55%	0.00%	1.00%	0.52%
	Window	4.41%	0.86%	0.76%	1.21%	0.86%	0.00%	0.31%
	CDU	0.52%	0.97%	0.07%	0.17%	0.41%	0.24%	0.00%
	From/To	EADI	ND	Air Spd	Altitude	MCP	Window	CDU
PNF MCP	EADI	0.00%	9.16%	9.16%	5.28%	2.10%	3.78%	0.51%
	ND	9.09%	0.00%	4.01%	2.10%	1.30%	1.53%	0.89%
	Air Speed	6.42%	4.52%	0.00%	1.91%	0.67%	1.88%	0.45%
	Altitude	5.50%	2.29%	1.14%	0.00%	0.73%	0.51%	0.19%
	MCP	2.03%	1.46%	0.38%	0.35%	0.00%	1.21%	0.45%
	Window	4.67%	0.95%	0.99%	0.57%	0.86%	0.00%	0.25%
	CDU	0.92%	0.86%	0.13%	0.10%	0.41%	0.32%	0.00%
	From/To	EADI	ND	Air Spd	Altitude	MCP	Window	CDU
PNF Manual	EADI	0.00%	7.03%	10.77%	4.99%	2.04%	2.60%	0.59%
	ND	8.10%	0.00%	5.19%	2.22%	1.28%	1.39%	1.14%
	Air Speed	8.28%	6.34%	0.00%	1.56%	0.73%	1.90%	0.45%
	Altitude	5.57%	2.80%	1.35%	0.00%	0.42%	0.55%	0.03%
	MCP	1.49%	1.70%	0.76%	0.31%	0.00%	1.04%	0.62%
	Window	2.91%	1.28%	0.90%	0.73%	0.97%	0.00%	0.31%
	CDU	0.80%	1.21%	0.17%	0.10%	0.38%	0.28%	0.00%
	From/To	EADI	ND	Air Spd	Altitude	MCP	Window	CDU
PNF Auto	EADI	0.00%	7.43%	10.18%	5.23%	1.89%	3.64%	0.41%
	ND	8.25%	0.00%	4.54%	1.82%	1.24%	0.83%	1.34%
	Air Speed	7.70%	5.23%	0.00%	1.75%	0.72%	1.58%	0.45%
	Altitude	5.95%	2.34%	1.10%	0.00%	0.62%	0.45%	0.10%
	MCP	1.89%	1.41%	0.89%	0.24%	0.00%	1.13%	0.55%
	Window	3.88%	0.76%	0.69%	0.65%	1.13%	0.00%	0.31%
	CDU	0.89%	1.34%	0.38%	0.03%	0.24%	0.45%	0.00%

Appendix B

Allocation of Visual Attention and Mean Dwell Duration

Means and Standard Deviations (Standard Deviation shown in parenthesis)

TABLE B-1. Proportional allocation of attention during the Downwind flight segment.

	EADI	ND	Airspeed	Altitude	MCP	Window	CDU
PF Baseline	.10 (.03)	.17 (.06)	.15 (.03)	.09 (.03)	.19 (.06)	.12 (.03)	.12 (.06)
PF MCP	.13 (.03)	.17 (.04)	.15 (.02)	.09 (.04)	.17 (.04)	.12 (.05)	.10 (.05)
PF Manual	.12 (.03)	.17 (.04)	.18 (.03)	.10 (.04)	.17 (.05)	.11 (.03)	.10 (.05)
PF Auto	.14 (.04)	.14 (.04)	.13 (.02)	.09 (.03)	.17 (.03)	.14 (.05)	.13 (.03)
PNF Baseline	.11 (.04)	.17 (.02)	.11 (.02)	.09 (.02)	.15 (.04)	.14 (.03)	.17 (.07)
PNF MCP	.13 (.03)	.14 (.05)	.12 (.01)	.09 (.02)	.13 (.03)	.16 (.04)	.18 (.04)
PNF Manual	.12 (.02)	.12 (.03)	.13 (.02)	.10 (.03)	.14 (.03)	.12 (.02)	.18 (.04)
PNF Auto	.13 (.03)	.14 (.04)	.12 (.02)	.08 (.01)	.17 (.03)	.12 (.04)	.18 (.03)

TABLE B-2. Proportional allocation of attention during the Final Approach flight segment.

	EADI	ND	Airspeed	Altitude	MCP	Window	CDU
PF Baseline	.26 (.08)	.18 (.07)	.13 (.03)	.06 (.03)	.12 (.04)	.16 (.09)	.02 (.02)
PF MCP	.35 (.06)	.19 (.10)	.12 (.02)	.03 (.01)	.08 (.02)	.12 (.05)	.01 (.01)
PF Manual	.25 (.11)	.13 (.05)	.33 (.12)	.04 (.02)	.06 (.03)	.10 (.07)	.01 (.01)
PF Auto	.28 (.10)	.17 (.09)	.14 (.04)	.04 (.02)	.08 (.03)	.18 (.10)	.01 (.01)
PNF Baseline	.21 (.07)	.23 (.08)	.09 (.03)	.08 (.04)	.09 (.03)	.12 (.08)	.03 (.02)
PNF MCP	.26 (.06)	.21 (.11)	.09 (.03)	.06 (.03)	.08 (.03)	.14 (.10)	.03 (.02)
PNF Manual	.23 (.07)	.20 (.07)	.13 (.05)	.07 (.03)	.08 (.03)	.11 (.06)	.03 (.01)
PNF Auto	.27 (.06)	.18 (.09)	.12 (.04)	.07 (.04)	.08 (.04)	.10 (.06)	.04 (.02)

TABLE B-3. Mean dwell duration (seconds) during the Downwind flight segment.

	EADI	ND	Airspeed	Altitude	MCP	Window	CDU
PF Baseline	.54 (.15)	.89 (.30)	.81 (.37)	.49 (.19)	1.01 (.52)	.70 (.24)	.69 (.33)
PF MCP	.62 (.24)	.86 (.22)	.75 (.17)	.48 (.18)	.87 (.17)	.63 (.25)	.48 (.28)
PF Manual	.53 (.16)	.82 (.23)	.92 (.26)	.51 (.26)	.83 (.28)	.61 (.30)	.47 (.29)
PF Auto	.75 (.26)	.76 (.28)	.67 (.18)	.47 (.20)	.78 (.15)	.79 (.35)	.66 (.17)
PNF Baseline	.54 (.11)	.85 (.18)	.57 (.13)	.45 (.10)	.77 (.22)	.74 (.25)	.94 (.42)
PNF MCP	.68 (.10)	.77 (.30)	.66 (.24)	.52 (.16)	.70 (.16)	.90 (.34)	.98 (.38)
PNF Manual	.61 (.10)	.64 (.20)	.69 (.15)	.57 (.15)	.78 (.19)	.63 (.13)	.96 (.26)
PNF Auto	.66 (.15)	.68 (.21)	.62 (.16)	.41 (.10)	.85 (.32)	.56 (.20)	.93 (.23)

TABLE B-4. Mean dwell duration (seconds) during the Final Approach flight segment.

	EADI	ND	Airspeed	Altitude	MCP	Window	CDU
PF Baseline	.83 (.10)	.81 (.27)	.65 (.098)	.58 (.13)	.94 (.29)	1.11 (.26)	.79 (.73)
PF MCP	.96 (.22)	.82 (.20)	.71 (.12)	.56 (.19)	.79 (.19)	1.33 (.38)	.72 (.42)
PF Manual	.90 (.50)	.77 (.31)	.93 (.26)	.54 (.18)	.85 (.32)	1.20 (.43)	.68 (.21)
PF Auto	.80 (.14)	.78 (.31)	.65 (.15)	.54 (.24)	.72 (.067)	1.14 (.30)	.59 (.28)
PNF Baseline	.70 (.13)	.78 (.20)	.61 (.10)	.58 (.17)	.67 (.12)	.78 (.21)	.70 (.29)
PNF MCP	.78 (.056)	.79 (.18)	.63 (.12)	.55 (.079)	.66 (.09)	.94 (.20)	.80 (.39)
PNF Manual	.78 (.17)	.78 (.31)	.73 (.17)	.60 (.18)	.76 (.19)	.87 (.25)	.72 (.23)
PNF Auto	.79 (.12)	.76 (.34)	.65 (.15)	.57 (.20)	.63 (.087)	.83 (.26)	.78 (.26)

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14. ABSTRACT
An airborne tool has been developed based on the concept of an aircraft maintaining a time-based spacing interval from the preceding aircraft. The Advanced Terminal Area Approach Spacing (ATAAS) tool uses Automatic Dependent Surveillance-Broadcast (ADS-B) aircraft state data to compute a speed command for the ATAAS-equipped aircraft to obtain a required time interval behind another aircraft. The tool and candidate operational procedures were tested in a high-fidelity, full mission simulator with active airline subject pilots flying an arrival scenario using three different modes for speed control. Eyetracker data showed only slight changes in instrument scan patterns, and no significant change in the amount of time spent looking out the window with ATAAS, versus standard ILS procedures.

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Approach spacing; Pilot eyescan; Eyetracker; Aircraft operations; Aircraft spacing

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